Mémoire

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Déterminants de l'hétérogénéité temporelle et spatiale de la pression de foreurs de tige sur maïs dans une région agricole du Kenya

Pour l'obtention du diplôme de Master Sciences et Technologies du Vivant et de l'Environnement

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Abstract

This study is integrated in a context of research on ecosystem services on pest regulation.

In the context of high population rural area in mid altitude Kenya, smallholders have diversified production systems and intensification is based on labor. In this situation, human pressure shapes a complex landscape with a very small grain.

The study was carried in Kajulu location in western Kenya, during 2011’s long rainy season.
We investigated the ability of such landscape to deliver pest regulation services. We studied the spatial and temporal heterogeneity of maize stemborers pressure, based on spatial monitoring of insect flight and damages at the field level, as well as surveys of farmers.

Landscape was described in scale units, from the natural elements framing the area to intercropped species in the field.

A very low infestation of stemborers was observed in the 27 fields spread in the whole area. *Busseola fusca* was the dominant stemborer, confirming its climatic and altitudinal preferences. Due to this low density of stemborers, natural regulation by parasitoids could not be observed.

Long rainy season started with a gap of more than one month; as a consequence, sowing dates and *Busseola fusca* flights were shifted. Fight peak was observed in June, with a high variability of caches among traps.

Surveys of farmers revealed that stemborers are not considered as a main pest in the area contrary to birds, rodents or baboons. There is no direct pest control against stemborers but cultural methods as tillage are employed against insects more widely.

In this situation, it has not been possible to observe heterogeneity in stemborer pressure and to relate it to landscape traits and agricultural practices.

Applied methodology and results are discussed in this report, with critical discussion and outlooks.

Contents

Introduction

Intensification of agriculture and industrial crop production on large areas has resulted in a simplification of agricultural landscapes worldwide. Expansion of agricultural land; converting natural ecosystems to simplified managed ecosystems, intensification of resource use, including application of more agrochemicals, are considered to be an important cause of the decline in farmland biodiversity (Tscharntke *et al.* 2005, Bianchi *et al.* 2006). On the contrary, in Southern countries, intensive agriculture refers to farming systems based on short fallow rotations or permanent cultivation in which farmers employ labor-intensive techniques such as irrigation, manuring and composting to maintain soil fertility, carry on a close interaction of crops and livestock, cultivate multipurpose crops,…. Agro-diversity can qualify these traditional agrosystems, in which farmers maintain a wide range of different plant species, either in individual fields or over the farm as a whole. (Conelly *et al*. 2000).This labor based intensification is associated to land pressure and high population density.

The species richness of all biotic components of traditional agroecosystems is comparable with that of many natural ecosystems. These systems offer a means of promoting diversity of diet and income, stability of production, minimization of risk, reduced insect and disease incidence, efficient use of labor, intensification of production with limited resources, and maximization of returns under low levels of technology (Altieri, 1999). The evolution and population dynamics of crop pests is also strongly linked with environmental heterogeneity in both space and time. It is recognized that crop placement, crop phenology and crop management practices constitute a shifting mosaic through time that are determinant of insect population dynamics (Kennedy *et al.* 2000, Thenail et al., 2009).

Natural habitats, but also managed ones such as fallows, hedgerows, woodlots, can constitute alternative habitats for crop pests and their natural enemies (Tscharntke *et al.* 2007). But most studies of biodiversity enhancement effects on insect populations have been conducted at the field level, rarely considering larger scales such as the landscape level and the crop-noncrop interface (Conelly *et al*, 2000).

The study aims to explore the properties of complex landscape in a high populated rural area in Western Kenya. Considering that there is an interlocking between the field and landscape, we are interested on properties and functions of this managed landscape on cultivated field.

Farmers, by their practices influence insect's biological model and their pressure at the field scale. Thus, we are interested on farmer's perception of them, because it might be not the same that researchers are considering.

Within this context, we investigated the ability of landscape to deliver pest regulation services. **We studied the spatial and temporal heterogeneity of maize stemborers pressure**, based on spatial monitoring of insect flight and damages at the field level, as well as surveys of farmers.

This question is about agronomy because we are interested in agro-ecosystems properties in one point of the landscape which is cultivated field. **This work aims to identify methods combining direct observations and farmers observations consideration.**

I. Conceptual framework and biological model

1. The study context

The study area took place during the long rainy season, between March and June 2011, in the Nyanza province of western Kenya (cf figure 1, 2). The study area corresponds to Kadero and Got Nyabondo sub locations (on Kajulu location), at 10 km north east, from Kisumu, the third largest city of Kenya.

The small scale farmers from 0,4 to 2,3 ha (Birman, 2010), have very diversified systems producing food crops as cereal, legumes, tubercles and fruits, rearing cattle, cows and goats and growing perennial plants for fuel and construction. Artificial fertilizer or pesticides are not easily available because of their price. This rural area is highly populated, with over 600 inhabitants per km² (Birman, 2010), that makes the landscape complex and with a very small grain. The main food productions are maize, vegetables and legumes. They are cultivated mostly intercropped together. Next to these rather diversified fields, sugarcane is the main cash crop production of the area.

This area was chosen because of its complexity. It is interfacing different ecosystems : semi-natural, pasture, but also different types of agro-ecosystems managed by smallholders (Jean-Baptiste, 2009)
This area is currently followed by Delphine Birman, Cirad PhD student who studies local knowledge on regulation processes involved in pest regulation. This study aims to bring further information with biophysical data on regulation processes. Two approaches are used to answer the question of spatial heterogeneity and stemborer pressure. Biophysical measurements are made, by landscape description and field observations, and surveys are made with farmers to know about their practices and knowledge about pests.

During the same period, another study was made by a CIRAD internshiper, Laure André, about spatial and temporal heterogeneity of bean's aphid pressure and natural regulation.

2. Maize stemborers and their natural enemies: the biological model

The staple food of Kenya is maize, and it is produced in every farm during the long rainy season, in the focused area, this is why, this crop was chosen for this study.
Lepidoptera stemborers are common pests in Kenya and considered by farmers as one of the main problematic pests in maize production (De Groote *et al.* 2001), this is why they were taken as indicator.
Moreover, a lot of research was made in Africa on stemborers and their natural regulation since the 80's (Calatayud *et al.* 2006). Today, stemborers specialists are based in Kenya, in ICIPE (African Insect Science for Food and Health) research organization.

Figure 1: localisation of Kenya in Africa

Figure 2: localisation of the studied area, in Kisumu district of western Kenya

i. Range of species and their hosts plants

In Africa, several stemborer species are pests of cultivated cereals plants like maize (*Zea mays*), sugarcane (*Saccharum* spp.), sorghum (*Sorghum bicolor*) or millet (*Pennisetum glaucum*). They may cause severe damage and are responsible of harvest losses (Polaszek *et al.* 2000).

These Lepidoptera can also develop on some cultivated and wild grasses as *Pennisetum* spp., *Sorghum* spp., *Cyperus* spp.,… (Otieno *et al*. 2006)

Busseola fusca, *Chilo partellus, Sesamia calamistis* are the main stemborers species on maize in Kenya. *C.partellus* is very polyphagous while *B.fusca* and *S.calamistis* are more specific, and particularly of cultivated plants.

Cultivated species								Wild host plants		
	Maize	Sorghum	Sugarcane	Rice	Millet	Wheat	*Pennisetum purpureum*	*Sorghum arundicaceum*	*Panicum maximum*	Other grasses
B.fusca	++	++	+	+	+			+		
S. calamistis	++	+	+	+	+					
C.partellus	++	+	+	+	+	+	+	+	+	+

Table 1 : *B.fusca, S.calamistis* and *C.partellus* plant hosts (adapted from Polaszek *et al*, 2000)

Presence and density of these species in Kenya, depends on climate and altitude in agroecological area (Ong'amo *et al.* 2006). *B.fusca* is the dominant specie next to Lake Victoria, in moist transitional agroclimatic zone (Ong'amo *et al.* 2006). (Cf figures 3, 4)

ii. Biology of *Busseola fusca*

Busseola fusca females can lay hundred of eggs, in groups of thirty to fifty, between the stem and the leaf sheath. Incubation period lasts one week. After hatching, young larvae feed on sheath and disperse to the adjacent plants. Then, they get into the stem and drill galleries toward the bottom of the plant. After 30 to 45 days and several larval stages, they drill an exit hole for the adult and pupate in the gallery. Pupation lasts 10 to 29 days. There are up to four generations per year. At the end of each rainy season, the last generation larvae diapauses in the stems to pupate at the beginning of the next rainy season (Polaszek *et al*. 2000).

Busseola fusca is known to be an oligophagous insect; it has a narrow range of potential host plants. Its preferred hosts are maize and sorghum and it is rarely found in napier grass (*Pennisetun purpureum*).
Interaction between its sensory system and chemical characteristics of its immediate environment make *B.fusca* recognizing and colonizing the variety of its host plants.
B.fusca is first attracted to his favorite hosts by the reception of plant volatiles, but it doesn't show any preferences between maize, sorghum and napier grass. Anyway, it is after landing that the moths show an oviposition preference for maize and sorghum making olfactory and tactile cues crucial in oviposition choice (Calatayud *et al.* 2008).

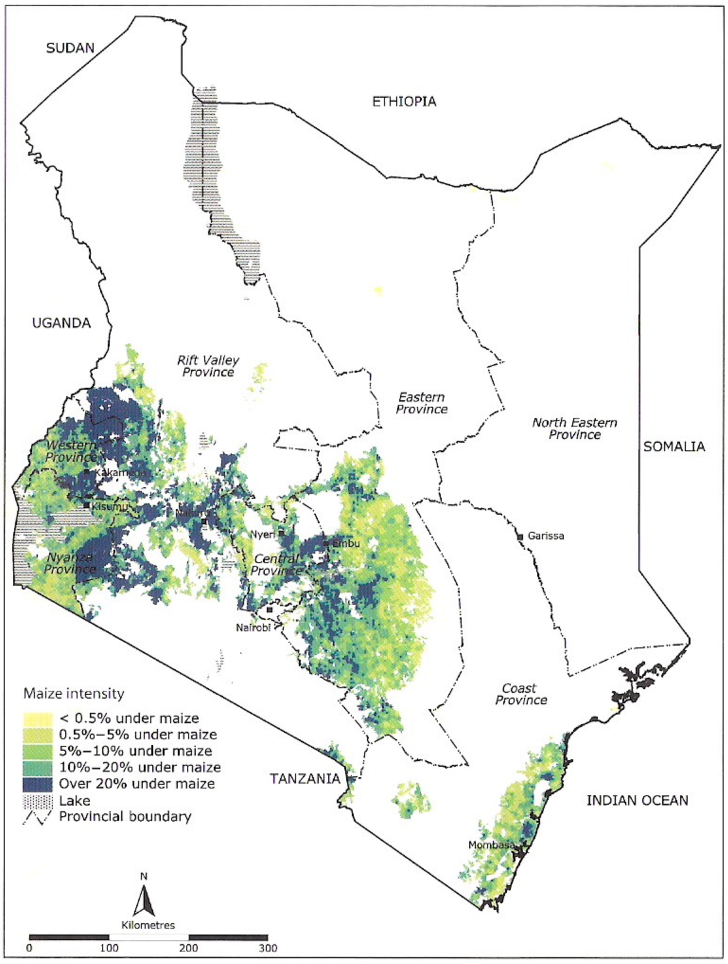


Figure 3: Distribution of maize in Kenya (in Hilbeck *et al*. 2004)

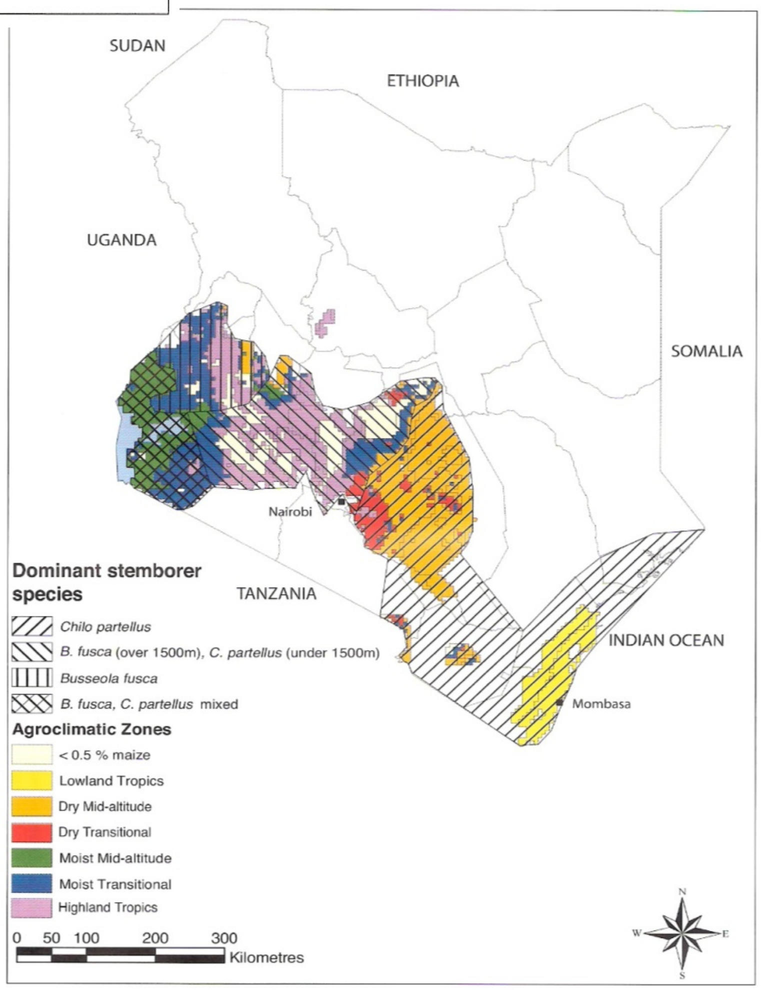


Figure 4: Main distribution areas of *B.fusca* and *C.partellus* (in Hilbeck *et al*. 2004)

iii. Natural enemies

At their different development stage stemborers have several natural enemies:

- Eggs are sensitive to climatic conditions and have predators like *Dorylus helvolus* (Heterogyna), *Cardiophorinae* larvae (Elateridae), and ants. In western Kenya, it has been observed that predators are responsible of the disappearance of more than 85% of *C.partellus* stemborers eggs on maize (Polaszek *et al.* 2000).
- Main natural enemies of larvae are parasitoids, mostly two Hymenopteras from the Braconidae family: *Cotesia sesamiae* and *Cotesia flavipes*. Parasitoid density is positively correlated with stemborer density on natural and cultivated areas (Mailafiya *et al.* 2010).
- Nematodes, bacteria (*Bacillus thuringiensis)*, fungi (genus *Aspergillus, Beauveria, Metarhizium,…),* viruses (Baculoviridae, Iridoviridae, Reoviridae, …), protozoa (species of the genus *Nosema)* can also regulate stemborers but are minor natural enemies (Polaszek *et al.* 2000).

3. Influence of agricultural practices on stemborers pressure at the field scale

Kfir *et al.* (2002) proposed methods that are applied or can be applied to manage stemborers development at the farm scale. Cultural control is the most relevant and economic method of stemborer control available for resource-poor farmers. Indeed, pesticides are not easily available and often not affordable for them. Moreover, resistant cultivars are not widely available, and biological control of stem borers is only partially successful and not manageable at the farm scale.
Cultural methods, including intercropping and habitat management, destruction of crop residues, sowing dates and densities manipulation are the first defense against pests for smallholders.

	Techniques	**Goal**	**Action's scale**	**Advantages**
Utilization of Synthetic Sex Pheromones	Males trapping	Monitoring to provide information for the timing of insecticide application	Area wide	Pheromones identified and available commercially
	Pheromone emission	Mating disruption	Area wide	Efficacity on *B.fusca*
Intercropping and habitat management	<u>Non host crops :</u> - Cowpea (Skovgard *et al.* 1997), - Bean (Songa *et al*. 2007), - Cassava	When the distance between two host plants increase, larva mortality increase	Field	Intercropping reduces the incidence of stemborers

	Push-pull strategy (Cook *et al.* 2007; Amudavi *et al.* 2008) : - Repellent plants (push) : Desmodium uncinatum, Melinis minutiflora - Attractive plants (pull) : *Pennisetum purpureum, Sorghum vulgare sudense*	*Melinis minutiflora* produces repellent volatile agents. *Pennsetum purpureum* and *Sorghum vulgare* act as trap plants	Field/Farm	*Melinis* increases *Cotesia sesamiae* parasitism. Push pull strategy reduces the incidence of stemborers *Sorghum vulgare sudense* is also a refuge for natural enemies. These grasses are fodder for cattle.
Management of crop residues	Tillage and Destroying stalks	Destroy diapausing larvae	Field/Farm	
Manipulation of sowing dates and densities	Early planting Space between rows	When the distance between two host plants increase, larva mortality increase	Field	

Table 2: Agricultural practices influencing stemborers incidence (conceptual framework from Kfir *et al.* 2002)

4. Influence of landscape traits on stemborers density and regulation

Stemborer infestations are indirectly influenced by landscape components around the field.
However, Girma *et al*. (2000) showed that hedges significantly reduce stemborers attacks in maize fields.

Uncultivated areas, such as fallows or field boundaries can also have an influence on stemborers infestations. For example, Cardwell *et al.* (1997), showed that there is an inverse relation between wild host plants around the field and its infestation by stem borers.
Wild host plants are available year long and can be alternative hosts for maize stemborers. Stemborers can feed on a wide range of specie, such as *Sorghum arundinaceum, Setaria megaphylla* for *B.fusca* (Otieno *et al.* 2006). Nevertheless, wild grasses can not be considered as reservoir or source of maize stemborers according to Ong'Amo *et al.* (2006a).

Moreover, same parasitoids can develop on cultivated and uncultivated habitats, and the specific diversity of plants in uncultivated areas have a positive influence on parasitoids diversity (Mailafiya *et al*. 2010)

II. Stemborer pressure in a spatio-temporal heterogeneity, managed by farmer communities.

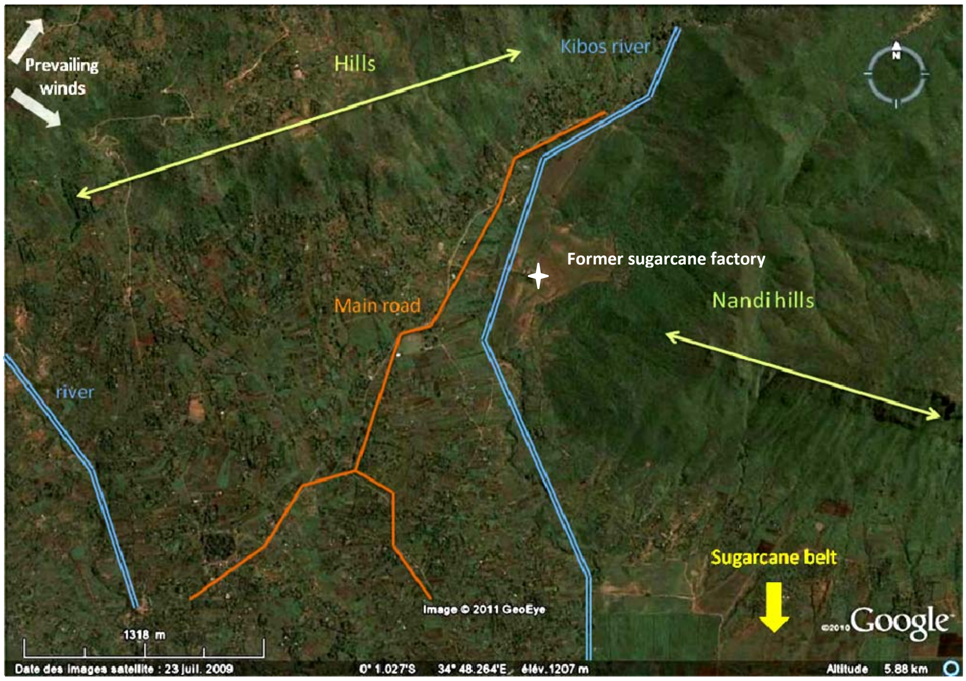
1. Experimental device

The studied area, in Kadero and Got Nyabondo measures 4 km², i.e. 3km from South to North by 1,3 km from West to East. Altitude is between 1208m and 1258m with a South to North gradient.

The target here is to describe landscape at different organization levels. It aims to spatialized studied fields and to show in time patterns influencing the studied biological model.

i. Strutural elements framing the area

Nandi Hills are the mountains closing the area at the north-east.(Picture 1)
At the east, Kibos river is a natural barrier for our study. It's coming from Nandi Hills and flows to Lake Victoria.
A road crosses these locations; it was originally built for the trucks going to the sugarcane factory. Nowadays, the factory doesn't exist anymore, but this main road remains.



Picture 1: Aerial view of the studied area (from Google earth).

ii. Land use: cultivated/non cultivated areas

The studied area is all cultivated except for some specific zones. On the north eastern part of Kibos river, there is a fallow collectively used for pasture. Before 2007, a sugarcane factory surrounded by sugarcane plantations was there; but after post-elections violence movements, the owner left the place and the land remains uncultivated (cf Picture 2)

The hills are not cultivated, but have been deforested for the last 20 years because of utilization of wood for fire and charcoal. Nevertheless, down slope, we can find woodlots and homesteads with some cultivated fields.

Picture 2: Sugarcane field in the foreground, fallow in the second plan and Nandi Hills in the back ground

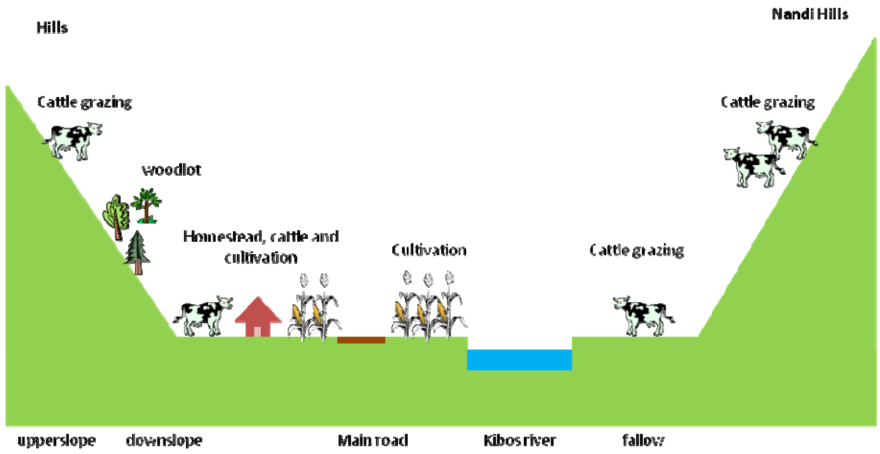


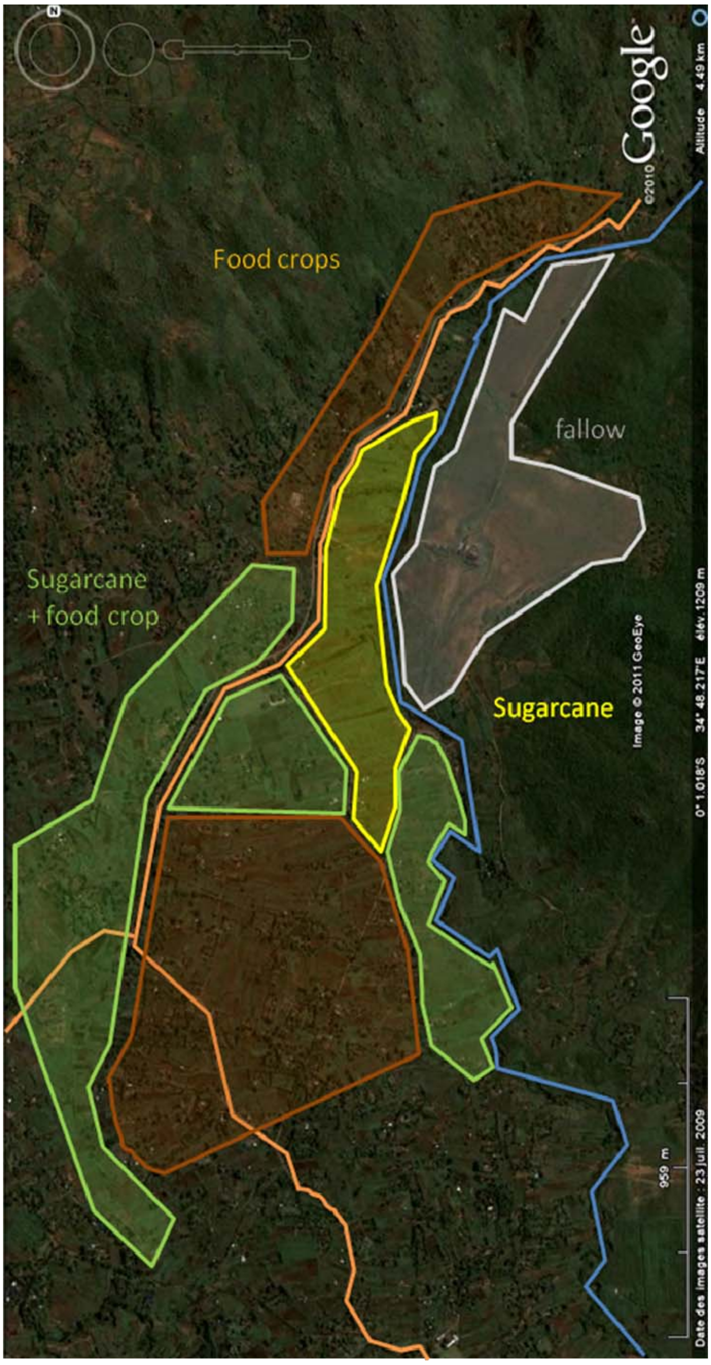
Figure 5 : Got Nyabondo (North-East of the area) landscape's profile.

i. Heterogeneity and landscape use type

We can distinguish a gradient in the land use. The component making this gradient is sugarcane. Indeed, it is mainly cultivated along the river. These rectangular fields are going down to the slope, and they are much wider than food crop fields (about hundred meters long and more than ten meters wide).

Going to the western part of the area, the land use is cultivation for food crop: cereals, legumes, fruit trees, but also trees for wood and for hedges. This area is characterized by the absence of sugarcane and the presence of a lot of trees and hedges.

Intermediate land uses exists in the southern part, where food crop fields and sugar cane fields are next one to each other. There is also some gardening.



Picture 3 : Representation of land use and landscape units (from Google Earth)

ii. Field local environment

Maize fields were selected following a transect from the north to the south on 3km.
First, 13 fields were selected for a survey in time (Figure 6). Then, 15 were added to collect more data but without any temporal evolution observation.

Maize is prevailing in the food crop production area whereas it is in minority in the sugarcane area. On the northern part of Kajulu, foothills and next to the river, resource availability for stemborers is also smaller because of less cultivated fields.

Every studied field, except 3 of them, was close to at least one maize and/or sorghum field. On the 27 studied fields, 10 were close to sugarcane fields (See Annex n° 1)

Dynamic of the field local environment

The landscapes structure is dynamic during the cropping season. Indeed, the sowing dates are staggered over time. In theory, the sowing period is supposed to start with the first rains, but in practice, a lag of several weeks can happen between the first and the last sowing dates. As a consequence, the resource availability in time is heterogeneous for maize stemborers.

Moreover, sugarcane is planted from April to November and takes 18 to 24 month to mature, so plantations and harvest periods are spread all year long.
Sugarcane plantations represent resource availability for stemborers while their leaves are stills smooth. While when a sugarcane field is harvested, we can assume than the created opening facilitate the stemborer movements in the matrix.

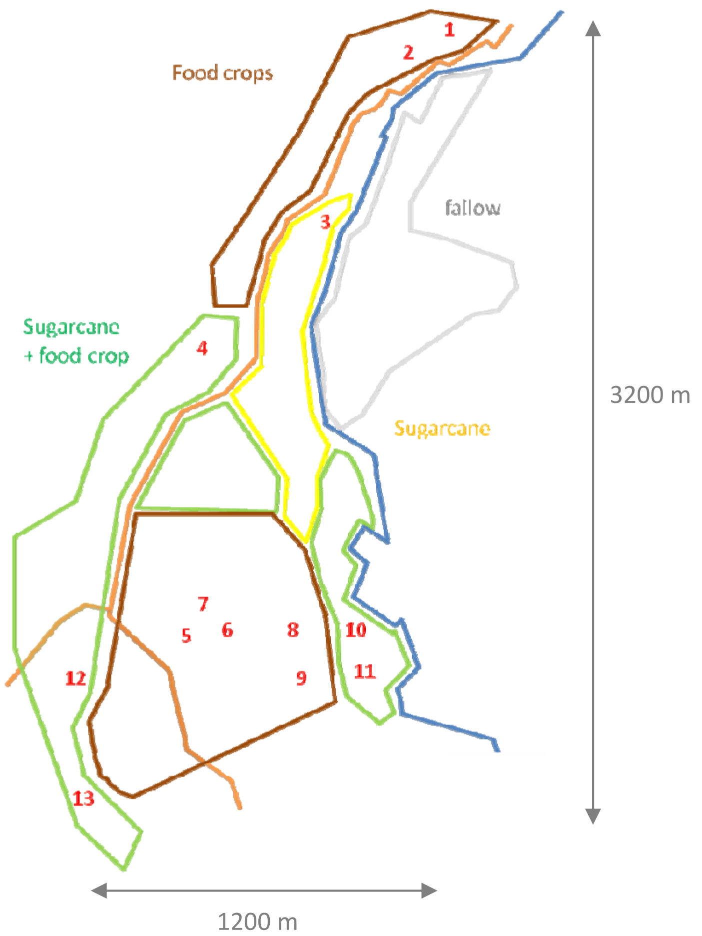


Figure 6: fields location within landuse units

iii. Heterogeneity on field practices: crops and inter-crops.

During this long rainy season, except in the sugarcane area, land was cultivated mainly with cereals: maize (*Zea mays)* and sorghum (*Sorghum bicolor)*; legumes: beans (*Phaseolus vulgaris)*, cowpeas (*Vigna unguiculata)*, green grams (*Vigna radiata)*; and also, some cassava (*Manihot esculenta)* and sweet potatoes (*Ipomoea batatas)*. Vegetables like kales (*Brassica oleracea)*, tomatoes (*Solanum lycopersicum)*, or pimentos (*Capsicum sp.)* are produced in home gardens or as cash crops.

On the field network, 17 were planted with maize intercropped with legumes and/or sweet potato and or/cassava and or/other crops (See Annex n°2). Moreover, some edible plants as *Amaranthus dubius* grow spontaneously and are not destroyed during weeding (cf picture 5)).

5 fields were planted with maize intercropped with sorghum and legumes, 4 were pure maize fields, and one was sorghum pure field.
Fields size is heterogeneous; the average size is about 458m², going from 64m² to 1615m².

Dynamic of resource availability in the field

Because of the lateness of the rainy season, sowing dates were very heterogeneous among farmers. In the studied fields, the earliest sowing dates started in February and the latest at the end of April. Nevertheless, farmers who sew end of April chose early maturity varieties and in June, all the fields were at the same phenological stage.

Hedges and trees

Depending on their localization (sugarcane area or food crop area), fields are surrounded by one or several hedges. They vary in term of species, height, length, and function.
The hedges are mainly composed with the following species: *Thevetia peruviana*, *Lantana trifolia* and *Euphorbia tirucalli.* But trees for wood (Eucalyptus, Grevillia,…) or fruits (mangoes, guavas, bananas,…), and a lot of spontaneous shrubs also made up the hedges.
In addition to fruit and wood production functions, they are planted to mark the boundaries of the property and to make a protecting fence against animals and thieves.

Density of trees and hedges is very high in the food crop production area, whereas it is less important in the sugarcane area due to the size of fields and the lower population density.

Napier grass is planted by some farmers around the field, in patch or in line the middle of the field. It has two functions: fodder for the cattle, and anti-erosive function on sloping fields (cf picture 6).

Trees for fruits: mangos *Mangifera indica*, guavas *Psidium guajava*, avocados *Persea americana*, water pears *Syzygium guineense,* and for wood: Eucalyptus *Eucalyptus spp*., Grevillia *Grevillea robusta*, *Markhamia lutea* ,… are also produced. They are grouped in woodlots, planted inside hedges or inside cultivated fields.

Picture 4 : Maize intercropped with cowpea and sweet potatoe

Picture 5: Maize field and surroundings; napier grass, trees and cassava

2. Surveys about agricultural practices and farmers knowledge of pests

i. Methodology

On April 2011, a first participatory seminar was organized to explain the goal of the study to the farmer's community (cf picture 7). Moreover, the aim of the seminar was to catch information about their knowledge on pests, their pressure and regulation, having a collective perception of it.
Seminar and interviews were traduced simultaneously from English to Luo and from Luo to English. (See Annex n°3).
After the collective participation of the farmers interview guides were prepared for individual interviews.
Two types of interviews were elaborated. A long one was made for the farmers with any other extra activity and a shorter one for farmers with other activities and who employ people to work on their fields.
The long interviews aimed to give information about agricultural practices for the studied cropping season and the previous ones as well as knowledge about pests.
The short interviews were focused on agricultural practices for the studied cropping season.

In June 2011, at the end of the study, another seminar was organized, to give a feed back of the work to the farmers and also, to get some more information about their perception of insects infestations for this rainy season in term of level of infestation and infestation in time in comparison to the previous ones.

ii. Local knowledge and agricultural practices

Kajulu farmers know about the stemborers because they attribute them a Luo name ("kundi").
Anyway, they are not considered as major pests unlike rodents, squirrels, baboons and birds that cause a lot of looses during sowing and before harvesting.

We could not determine what a high or a low pressure of stemborer is for farmers. Stemborers are considered "problematic" when they are in maize cobs even if there are few. So, independently of their density, pressure is more about temporality: stemborer damages are problematic at the end of the crop cycle, when maize is ready to be harvested. Anyway, they could not estimate loses caused by them, neither compare attacks between rainy seasons and between years.

Farmers don't have any traditional direct pest control against stemborers and pesticides are not easily available and affordable for them. Anyway, some agricultural practices aim to prevent the crops from these insects (See annex n°4).
First of all, two tillage are made before sowing, and a few weeks separate the two diggings notably to expose some insects to the sun and drought and destroy them.
Before, farmers were used to burn the stems after harvest, and this was destroying insects inside the stems. Nowadays, farmers let stubbles to decompose in the field or use them to make compost (mixed with cow dung). As a consequence, they observe more insects and damages since the change on practices.

Push-pull strategy elaborated by ICIPE was introduced to young farmers during "farming courses" at school. Some farmers also learned about it in various seminaries.
Nevertheless, they are experiencing it for a short time, so they cannot tell if there is a changing or not in stemborers infestation on maize field.

Picture 6: collective seminar

Farmers observe that local varieties are more resistant or less attacked by stemborers than hybrid ones. However, in our study, 60% of them (the wealthiest farmers) cultivate hybrid varieties now.
They also observe that sorghum is more sensible than maize to stemborers, this is why they tell that it is better to avoid mixing these two species.

Concerning the spatial distribution of insects on the fields, the relation is made between insects pressure and soil fertility. Indeed, in fertile parts of the field, maize is healthier so more suitable for insects.
Another relation is made by farmers with trees. The trees, especially Eucalyptus, are very competitive for water and make the crops weak but they also provide favorable shade and humidity for insects.

About the temporal distribution of stemborers attacks, if farmers tell that insects spend the dry season on the soil and also that they can come from far, it was not possible to determine if there are more insects during the long or during the short rainy season. In the same way, it was not possible to determine when insects cause more damages during the cropping season. Anyway, stemborers are often observed on the cobs, this confirms that late flights are usual.

3. Biological model observation

i. Meteorological conditions

Meteorological information for this rainy season was provided by KESREF (Kenya Sugar Research Institute) meteorological station. This station is located in Kibos, at 4km south-east from Kajulu. It gives information about general rainfall for this rainy season; however, localized events are missing because of the distance.

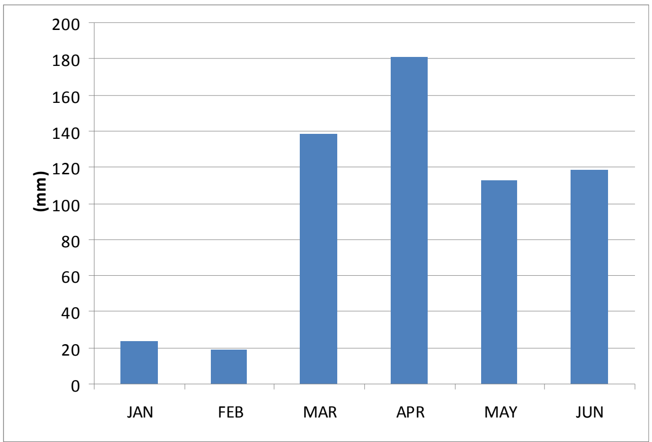


Figure 7: Rainfall in KESREF meteorological station, from January to June 2011

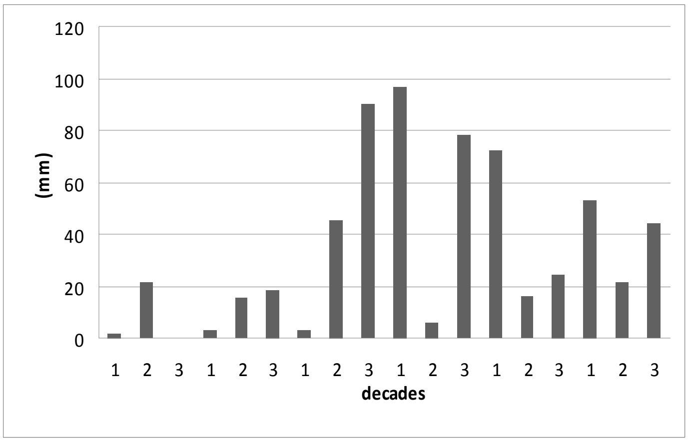


Figure 8 : Rainfall recorded in KESREF meteorological station, from January to June 2001. Representation by decades.

These graphic show us that long rainy season started in 2011, in end of March. The rainfall was the higher in April and started decreasing in May.

The rainfall was not regular, indeed, on the second decade of April rains were very few compare to the first and the third ones. This explains that farmers were confused for the date of sowing and that some of them had to sow at the end of April.

Rains were very punctual; a few heavy rains (cf table 3) made the rainfall of the decade and of the month.

days	JAN 11	FEB 11	MAR 11	APR 11	MAY 11	JUN 11
1	0,0	0,0	0,0	83,5	0,5	7,3
2	0,0	1,1	0,0	5,1	0,0	0,5
3	0,0	0,0	0,0	0,0	0,0	0,0
4	0,0	1,8	0,0	0,0	9,4	8,9
5	0,0	0,0	0,0	0,0	1,8	5,0
6	0,0	0,0	0,0	1,4	0,7	0,0
7	0,0	0,0	2,5	0,0	2,4	0,0
8	0,0	0,0	0,4	0,0	7,5	27,3
9	0,7	0,0	0,0	6,9	36,8	4,0
10	1,1	0,0	0,0	0,0	13,3	0,0
Total D1	1,8	2,9	2,9	96,9	72,4	53,0
11	0,0	0,0	0,0	0,0	0,6	2,5
12	0,0	0,0	0,0	0,0	8,7	5,5
13	6,4	0,0	1,3	0,0	0,0	1,9
14	1,5	2,5	1,4	0,0	0,0	0,0
15	4,2	0,0	0,0	1,2	0,0	4,5
16	0,0	0,0	7,9	0,6	0,0	7,2
17	0,8	0,0	18,6	0,0	0,0	0,0
18	1,3	12,7	0,3	0,0	0,0	0,0
19	0,0	0,6	10,7	0,0	2,4	0,0
20	7,2	0,0	5,4	4,0	4,2	0,0
Total D2	21,4	15,8	45,6	5,8	15,9	21,6
21	0,0	0,0	8,2	21,6	0,0	13,5
22	0,0	0,0	10,0	22,0	3,6	20,2
23	0,0	0,0	1,2	3,6	0,0	0,0
24	0,0	0,0	0,9	7,8	0,0	0,0
25	0,0	0,0	0,9	0,9	0,0	0,0
26	0,0	0,0	0,0	0,5	0,8	0,0
27	0,0	0,0	49,0	0,0	18,9	0,9
28	0,0	0,0	17,3	1,8	1,2	3,1
29	0,0		0,0	17,5	0,0	6,4
30	0,0		1,5	2,5	0,0	0,0
31	0,0		1,2		0,0	
Total D3	0,0	0,0	90,2	78,2	24,5	44,1
Total per month	**23,2**	**18,7**	**138,7**	**180,9**	**112,8**	**118,7**

Table 3: Daily rainfall in KESREF meteorological station, from January to June 2011

i. Field observations and stemborer pressure

Samplings were made in the 13 selected fields to know their infestation level. Observation were done every week between May and June to study spatial and temporal evolutions of infestation.
Fourteen fields were added to the network and observed during the same week on May to complement the network and check if some information were not missing in the first one.

The survey of the 13 fields was organized in the week with 4, 4 and 5 fields observed per day.

Sampling method

50 plants were observed per field; 10 plants were randomly observed following 5 lines. (Overholt *et al.* 1994)

Picture 7: illustration of the sampling method

Collected information was the number of attacked plant and their localization on the transect. The level of infestation of attacked plant was also collected using a scale:

1: presence of eggs
2: damage of larvae on leaves
3: dead heart or exit hole (cf picture 9, 10)

When exit hole was observed, the stem was opened to collect the larvae or pupae and rear it on the lab. Collected data was the number of stemborers per plant and its development stage.

At the same time, information about maize phenological stage, maize height and density (distance between plants in the line and between rows) were taken, as well as geographical information, type of soil and the size of the field.

When napier grass was planted in the field or around, it was also observed. Dead hearts were the attack symptoms to look for.

The survey of the 13 fields was organized in one week to observe 200, 200 and 250 plants per day.


Picture 8 : Stemborer first damage


Picture 9: Stemborer exit hole

Stemborer pressure

This rainy season, in the studied area, stemborers pressure was very low in the plants. From the beginning to the end of the field observations, only very few stemborers larvae were found. The average infestation level was 0,8 attacked plant per observed field (in 27 fields), varying from 0 to 5 attacked plants per field (Cf table 4) and any stemborer was found in napier grass. These very low numbers can't allow us to make statistical analysis.
The complementary network also confirms that the stemborer pressure was very low in the whole area.

Field id/ Observation date	28.04.11	02/05/2011 week	09/05/11 week	16/05/11 week	23.05.11 week
1			**5**	**5**	
4		0	0	0	
5		0	0	**1**	
6		0	0	**1**	
7		**5**	**2**	**3**	
8	0	0	**1**	0	
9		0	0	**1**	
10		0	0	0	
11		**2**	0	0	
12	0	**2**	0	0	
13		0	0	0	
14					**4**
15					0
16					0
17					**1**
18					**1**
19					0
20					0
21					0
22					0
23					0
24					0
25					**1**
26					**1**
27					0

Table 4:Number of attacked plants per 50plant samplings per field per week

One larva or more were found in the attacked stems. The 57 insects (larvae and pupae) were reared in artificial diet (Songa *et al*. 2001) until adult stage, labeled and sent to ICIPE for identification by Boaz Musyok.

Identifications confirm *Busseola fusca* as the main stemborer specie in the area. However, two *Sesamia nonagrioides* and two *Chilo partellus* were also found. *Sesamia nonagrioides* were localized at the lower part of the area, next to a stream, in their favorite habitat.

We couldn't obtain any parasitoids. We can suppose that it is because their presence is depending on stemborers density. As stemborers were rare natural regulation with parasitoids was low.

ii. Sampling on wild grasses

Thanks to the presence of Bruno Le Rü, (IRD/ICIPE entomologist), the 23th of May 2011 was devoted to observation of stemborers on wild grasses. The attacked plants, recognizable by dead hearts (See picture 10) were dissected to find the larvae and send it to ICIPE for rearing and identification.
During the sampling in a wet place in the south of the studied area, stemborers such as *Sesamia nonagrioides* or *Sciomesa piscator* were identified at larval stage on *Cyperus spp*., *Bracharia sp*., *Cynodon sp*., *Panicum maximum*,… These species are not pests for maize and sorghum but they have the same natural enemies in common with maize stemborers.

iii. Monitoring *Busseola fusca* adult using pheromone traps

A network of funnel traps with specific pheromone for *B.fusca* was implemented to study temporal and spatial variations of *B.fusca* flights during the monitoring period.
Thirteen *B* traps were spread in a 3200 meters transect from South to North and 1200m transect between West and East, respecting prevailing winds See picture 11).(

They were placed on wooden sticks at 1m50 high (Critchley *et al.* 1997) and at more than 100m from each other to avoid interferences (Critchley *et al.* 1997). Wooden sticks were protected with oil to avoid termite damages.
Traps were placed at the very beginning of May, to try catching the first moths flights.
They were checked every week, pheromones changed every 2 weeks and insecticide every 3 weeks.

The scored information is the number of caught moths per trap, per week. At each observation, maize phenological stage was registered.
From May to June, 7 observations were made per trap and the survey will continue until the harvest.
In the 20th of June 2011, 3 traps were also placed in KESRE, on Kibos Sugarcane belt, to observe if the area can be a source or a sink for *B.fusca.*

The traps 9 and 10 were broken during the survey and have not been working for one week. But event took place in May.

Picture 10: Dead hearts on wild grasses

Picture 11: A pheromon trap placed in a field

Dynamics of flights

With regard to the pheromone traps, we can see an evolution in *B.fusca* adult populations. Indeed, in May, any *B.fusca* was found in the traps. But, from June, the number of captured moth went increasing. The flights started very late in the season and in the maize cycle, after tasseling, when silks were visible. Because of the presence of some larvae in cereal stems, flight may have occur before our observation, but with little intensity.

Observing these late flights, we can assume that stemborers will cause some damage on maize cobs. However, we did not observe the presence eggs on the 16th June observation (last control).

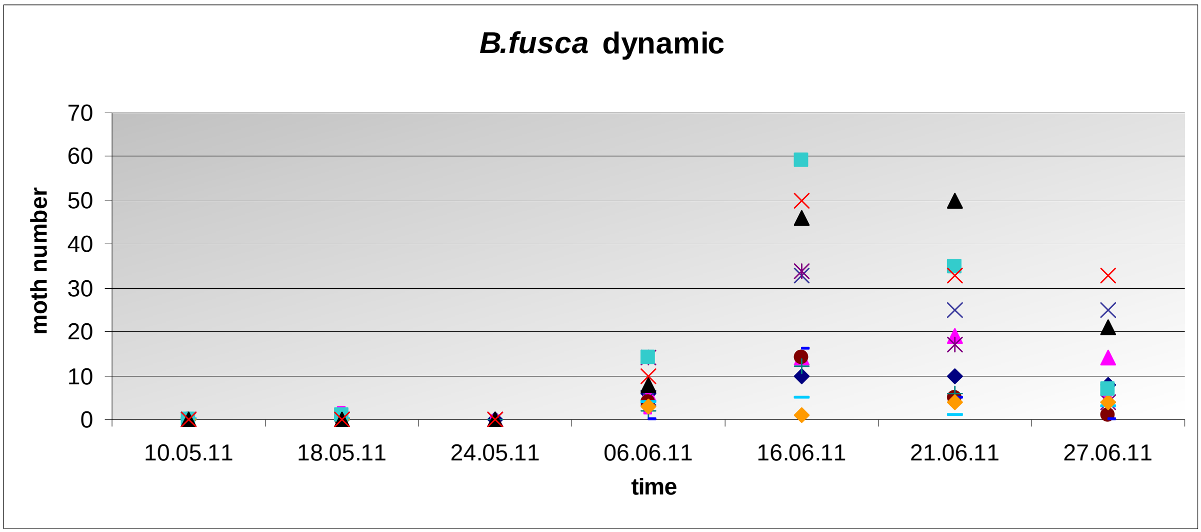


Figure 9 : *B.fusca* flights evolutions (moth number per trap per week)

Flights started everywhere, in each trap at the same moment, reached a peak one week at the observation of, the 16th of June, decreasing after. This pattern is the same for all the traps.

However, if we decompose catches of each trap, we can see few differences in flights kinetics (See annex n°5).

Some catches, as for the trap number 3 or number 10 increased until the 21st of June, and decreased the 27th, while others, as 11, 1 or 6 started decreasing before, from the 21st of June.

Finally, for the traps catching the fewer amount of moths stagnated without decreasing.

Moreover, we can observe that there is a high variability between the different traps. During the peak, some traps catch more than 50 moths (traps 11, 12, 13), whereas others caught less than 10 moths (trap 9, 10,…).

	06.06.11	16.06.11	21.06.11	27.06.11
+	5, 11	11	12	13
		13	11	4
	13	12	13	12
	12	5	4	3
	1, 3	4	3	1
		8	5	11
	4	2, 3, 6	1	2
	6, 9		7	5, 7, 10
			6, 8	
	10	7		
	7, 2	1	2, 10	9
		9		6
-	8	10	9	8

Table 5 : *B.fusca* catches hierarchy per trap, per week for the 4 last monitoring observations (each number representing a trap identification)

There is variability between the traps, and this Table 4 shows that the hierarchy between the traps is almost always the same. Facing this observation, we can elaborate several hypothesis to explain the variability of catches among traps.

First of all, Traps 1 and 2 were located in the northern and higher part of the area (1250m), whereas Trap 3 was located in the sucarcane production area. In these locations, resource availability is lower; this can explain that these traps caught fewer moths than others. However, the distance between Trap 1 and Trap 2 was less than 100, so they could eventually interact, explaining that moths are “diluted” in these two traps.

Traps 5, 6 and 7 were also close to each other. That can eventually explain the low catches of moths.

Traps 12 and 13 were relatively isolated from the rest of the group. They are those which caught the higher amount of moths and were located in a food crop and sugarcane production area, combining resource availability for stemborers and an opened landscape.

However, the trap 11 was not so isolated and caught as many moths as traps 12 and 13. Trap 11 was in the same kind of landscape than Trap 10, but this one caught very few moths during all the monitoring period.

Traps 8 and 9 also caught very few moths while they were located in the food crop production area with a majority of maize in the landscape. Is it because the landscape is not so open, so moths cannot receive emissions of pheromone.
Moreover, it is difficult to evaluate the effect of wind in each trap, and local climate events can entirely modify the area covered by pheromone emissions.

Therefore, it is difficult to relate trap location and the caught moths density and we cannot say if catches heterogeneity comes from an heterogeneity on stemborers presence in the area or not.

Distribution of flights in time

We observed that the attack on the field was very low, and the flight very late and massive.
We can suppose that stemborers life cycle have been shifted because of the rains and the sowing date, and therefore, the resource availability.
No measurements have been made in this area before 2011, so we cannot tell is this is exceptional or usual. Very few data are available in the literature. Paul-André Calatayud informed us (pers. comm.) that between April and September 2007 trapping in Rift Valley (1850 m) reveals that *B.fusca* moths can fly during this whole period reaching peaks with more than 130 moths per week and per trap at the end of June.

Analyzing surveys and seminars done in Kajulu, farmers said that if stemborers were not a main problem for them, the damages they had from stemborers were on the cobs. Thus, we understand that low pressure of stemborers and late flights are common.

III. Discussion and outlook

1. Limitations of the methodology

Spatial and temporal

First of all, we point out that the number of studied fields was not sufficient for a study that aims to investigate several variables. With this weak amount of fields, it is not possible to statistically relate pest pressure with recorded variables.

Time is another limitation of the study; it took place during only one rainy season, and not until the end of the cropping season. Traps are still on the fields, but field samplings were stopped before harvest, so information about damage on cobs will not be available.
To provide exploitable results, the study should be repeated several years (three at least) and during the two cropping seasons.

Traps

If other studies are made in the future, geographical repartition of traps should be improved. Indeed their location was chosen when visiting the farmers at the beginning, without taking care enough of their spatial localization. Moreover, it would be interesting to place some traps in a different area (like it has been done in KESREF), earlier in the cropping season, to compare flight dynamics and densities among them.

Bibliography does not provide enough information on pheromone emission and reception distances. As a consequence, it is difficult to estimate when two traps are in interaction because too many variables like wind intensity and direction influence pheromone emission. This means that pheromone traps give information about flight dynamics but not quantitative information about stemborer densities around the trap.

Another questioning is about the origin of the *B.fusca* moths. A lot of them were trapped in non infested fields. And even if the field was surrounded by other maize fields, these ones were not either very attacked because we could see that globally stemborer pressure Kajulu was very low.
We can wonder if these moths were coming from the area or if they were coming for farther, from other maize and sorghum production areas. Indeed, moths have the capacity to fly until 6 km (Pascal Campagne, personal communication).

2. Review on results

Quantitative data on landscape components

In this study, quantitative data on landscape components and biodiversity is missing. Shannon index is an example of biodiversity index. It was not calculated because uncultivated areas are very few, but for future studies it could be interesting to calculate it for biodiversity of hedges for example.

Stemborers pressure

None parasitoid was observed. Stemborer density was low while parasitoid presence is correlated with it. Songa *et al*. 2006 showed that parasitism of *B.fusca* and *C.partellus* by *C.flavipes* is generally under 10% in mid altitude Kenya, which is a low rate compared to other agroclimatic zones of Kenya.

B.fusca and stemborer were not found in napier grass. We found in literature (Le Ru *et al.* 2006) that misidentifications could happen in previous studies (Polaszek *et al. 2*000). As a consequence, *B.fusca* capacity to develop on napier grass is not confirmed.

Adult *B.fusca* is a flying insect and bibliography does not give information of population flight dynamics neither on their dispersion. We don't know yet capacities of movement of these insects except that some of them were found at 6km from their realizing place (Pascal Campagne, personal communication).
We can wonder if flying insects like noctuids are good indicators to study pressure heterogeneity on time and space.
We can also invert the question and wonder if the scale of the study area (4km² area) is appropriate to study stemborers pressure heterogeneity.

3. An outlook: spatial analyze

Recent studies use other tools to spatially analyze insect pressure at a territory scale.
Geographical Information Systems (GIS) allow landscape mapping and the drawing of concentric buffers around focused field to relate covered landscape descriptors with insect population distribution (Ricci *et al.*2009).
However, these tools are applied in large scale landscapes such as apple orchards on southeastern of France (Ricci *et al.*2009) or winter crops fields in Germany (Roschewitz *et al*.2009). The radius of buffers covering landscape descriptors was going from 50 to 500 meters in Ricci *et al.* (2009), and from 1 to 3 km in Roschewitz *et al.* 2009.
Therefore, these methods are not immediately applicable in the studied context where fields are very small (average surface: 458m²). More precise tools need to be adapted for these small units.

The studied landscape is very dynamic because of two rainy seasons and the combination between annual crops and perennial crops like trees and hedges, sugarcane covering a field for several months. On the contrary, landscapes studied in France and Germany are not very dynamic: orchards are perennial and annual crops are produced in monocrop open-fields.
Therefore, spatial and temporal scales are one of the main constraints for adaptation of spatial analysis from large-scale landscape units to small-scale landscape units. This should be analyzed in the next future.

4. Farmer's perception of stemborer pressure

Ten years ago, two studies were published about farmer's perception of stemborer pressure.
The first study was a participatory research was conducted in different agro-climatic zones of Kenya, about farmers demand on insect resistant maize varieties (De Groote *et al.* 2001). Farmers categorized resistance to stemborers criteria as "less important", compared to other criteria such as early maturity, high yield potential or resistance to drought.
Similarly, stemborers were classified after Striga and weevils on storage. Stemborers seem to be more problematic in high potential areas compare to other agro-climatic zones.
However, farmers did not rank pest problems among their first maize production constraints. For them, cash, fertility or rain problems were important.

The second survey made in coastal Kenya, was relative to farmer's perceptions of importance, control methods and natural enemies of maize stemborers (Bonhof *et al*. 2001).
In this area, stemborers were considered as important pests, and chemical control was quite popular. Moreover, some farmers could recognize stemborer moths and eggs.
These results are surprising because Kenyan coast is considered for maize production low potential area where stemborers are responsible of "only" 9% of losses. In comparison, in moist mid-altitude zone of western Kenya, stemborers are responsible of 13% of harvest losses (De Groote *et al.* 2004).
Perception of stemborer losses for these farmers in opposite parts of Kenya is very interesting. When resource is scarce, a small amount of loss has a huge impact for food production.
On the other hand, *Cotesia flavipes*, the stemborer parasitoid was introduced in 90's in Coastal Kenya (Mailafiya *et al.* 2010). It was released from several times and from several locations. Indeed, we can suppose, that farmers of the area have certain knowledge on stemborers because of research centers action for a long time.
Thus, the addition of new knowledge by the influence of external information brought by research centers, or even NGO's, changes perception of farmers on pests.

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TABLE OF APPENDIXES

ANNEX N°1: Surrounding of studied fields

	Trees and Hedges			Composition of surrounding fields			
Field id	Napier or wild grasses	Trees	Hedges	Maize&/or Sorghum	Sugarcane	Other	fallow
1					+	+	
2					+	+	+
3	++				++		
4	+	+	+	++	+	+	
5	++	++		++		++	
6		++		++	+	++	
7		++	+	++		+	+
8		++	++	++	++	+	
9		++	++	++		+	
10		++	++		+	+	+
11		++	+	++	+		+
12	++			++	+	++	
13	++			++	++	+	
14		++	+	++		+	
15	+			++		+	
16		+		+		+	+
17		+		++	+	+	
18		++		++			
19		+	+			++	
20				+		+	+
21	++			++			
22		+		+		++	
23		++	++	++		+	++
24	+	+		+		++	++
25	++	++		++			+
26				++			+
27				++			+

+ presence in one border ; ++presence in more than one border

ANNEX N°2: Specific composition inside fields

		Specific composition inside the field : crops and intercrops										
Field id	Field size (m2)	Maize	Sorghum	Beans	Cowpea	Other legumes	Sweet potatoe	Cassava	Other crop	Napier grass	Banana	other tree
1	1210	+	+									
2	552,5		+									
3	149,5	+						+		+		
4	300	+		+	+	+					+	
5	282	+		+	+	+	+	+	+			
6	760	+	+	+	+	+		+				
7	429	+	+	+								
8	1615	+		+							+	+
9		+		+								
10	690	+		+							+	+
11	660	+	+	+								
12	595	+	+	+								
13	90	+		+								
14	72	+										
15	64	+						+				
16	900	+	+	+					+			
17	496	+		+								
18		+									+	+
19	198	+				+						
20	594	+			+	+						
21	115	+										
22	200	+		+		+						
23	510	+				+	+				+	
24	357	+	+				+					
25	238	+			+		+			+	+	
26	120	+		+			+					
27	264	+			+							

+ presence of the species inside the field

ANNEX N°3: extract of the 21st March collective seminar transcription

(…)

WOMAN 2: anto penjo mane apenjo?

The question that I had?

PAUL **yes,**

WOMAN 2: en ni an ase puro bando gi oganda,

yes that I have cultivated maize and beans,

PAUL: eyi niang koso ebath niang?

Inside the sugar plantation or besides it?

WOMAN 2: ebathe, kaka ma puoth niang,

besides it, like this is the sugar plantation.

PAUL: kaka macha opang cha?

The way that farm has been arranged?

WOMAN 2: h, to mano be puotha maonge gima opogo, odumba ne ochiek malich plus oganda, to problem mane aneno ka niang nyalo bet na machiegni gi puodho, animaals maricho. Ma ok nage'eyo gima omiyo animls maricho oero niang, but not insects.

Yes, and this is also my farm with no much difference, the only problem that I saw when sugar cane can be next to my farm, is because of bad animals, and I don't know why these animals like to be in the sugar cane? But not insects.

DELPHINE: **which animals?**

PAUL: le mage?

(…)

WOMAN 2: ma muodo bando kata oganda ka oganda ose gik , eh, le mag animals

the ones that eat maize and beans when they're ready. The animals.

PAUL: so **she is saying, there are some animals and rodents, and she has observed that when she**

PAUL: **that she has observed that when she plants her maize next to the sugar cane, it's not the pest problem that she will see, but the fact that this animals like living in the sugar cane, so they'll come and eat the roots of the maize, yea,**

ANNEX N°4: Agricultural practices during the long rainy season

After harvest of the short cropping season crops, the land is first **ploughed** in December. After letting the land to dry in the sun, a second plowing is generally done in February. Then, the soil is ready for plantation. The plowing is made with a hoe, or some cases, and only for the first plowing, with oxen.

Three different hoes for tillage and weeding

Then, when the **first rains** are coming (usually mi-february), farmers start to **sow** cereals (maize or/and sorghum), in line or randomly. One week after, when the maize emerges, legumes like beans or cowpeas are sawn between the raws.

Then comes the period of **weeding**. Fields are weeded with the same kind of hoe as for plowing. The weeding is made after the rain, when the soil is easier to work.
There are usually two weeding per field. The first one starts when the maize is 50 cm, and the second one, when the weeds are growing again, so depending on the climate and not the crop development.

About **fertilization**, practices differ among farmers.
Some farmers use artificial fertilizers, others only cow dung, and some others apply both.
We observed two ways to apply cow dung. It is sometimes applied between the two plowings, so it is incorporated to the soil during the second plowing. Some other times, it is applied during the plantation, in the hole where the seed is going to be putted. Decomposed cow dung is preferred not to burn the young crops.
Some farmers also apply fresh dung during the crop production, when they have a lot of cows or not enough space in the pen to let the dung to decompose.

About artificial fertilization, it is applied by farmers with sufficient income to buy it, or by farmers who don't have any cows. It is applied during the sowing, a little spoon by hole.

Fertility problems are visible during the cropping season by the presence of Striga, a cereal parasitic weed which causes harvest loses to farmers.

Striga parasiting maize

The main pests for maize are baboons, birds and squirrels coming to eat mature maize cobs before the harvest. In term of **crop protection,** some farmers apply cow dung or plastic bags to protect the cobs from the little mammals and the birds.

About insects, stemborers and caterpillars are observed by the farmers but they have no mean to control them. However, some farmers explained that the time between the two plowings before the plantation is supposed to kill insects of the soil.

The **harvesting** is in July. Les legumes are first harvested because their development is shorter than maize one. Maize is started to be harvested when it is still green to be consumed boiled or grilled. When it is dry, the whole field is harvested.
Wastes of crops are usually given to the cattle as forage. When there are not cattle in the farm, remaining stems and leaves are cut in little pieces and let on the soil as manure. They are quickly decomposed with the help of termites.

Some farmers keep seeds from one year to the other. This is the case with local **varieties** known as Nyamula (yellow) or Nyaluo (white).
Some farmers prefer to cultivate hybrid varieties so they have to buy new seeds every year.

ANNEX N°5: Detail of stemborers flights

Trap_id	10.05.11	18.05.11	24.05.11	06.06.11	16.06.11	21.06.11	27.06.11
1	0	0	0	6	10	10	8
2	0	2	0	2	14	4	5
3			0	6	14	19	14
4	0	0		5	33	25	25
5	0	0	0	14	34	17	4
6	0	0		4	14	5	1
7	0	0	0	2	12	6	4
8	0	0	0	0	16	5	0
9	0	0		4	5	1	3
10	0	0		3	1	4	4
11	0	1		14	59	35	7
12	0	0	0	8	46	50	21
13	0	0	0	10	50	33	33

Trap monitoring: moth's caches per week per trap